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Cost and Performance Report

(MR-200809)

ALLTEM Multi-Axis Electromagnetic Induction System Demonstration and Validation

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ACRONYMS AND ABBREVIATIONS

AHRS	attitude heading and reference system
ALLTEM	On-Time Time-Domain Electromagnetic System
APG	Aberdeen Proving Ground, Aberdeen, MD
B	blank
BTG	Blind Test Grid
C	clutter
ΔN	difference in northing from correct location
ΔE	difference in easting from correct location
DoD	Department of Defense
EM	electromagnetic
EMI	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
GPS	Global Positioning System
HEAT	high explosive anti-tank
Hz	Hertz
IDA	Institute for Defense Analysis
MEC	munitions and explosives of concern
m/s	meters per second
MSE	mean-square error
NOMEX	fiberglass facing over plastic honeycomb core material
O	ordnance
Pcc	percent of correct classification
Pd	percent of detection
Pfa	percent of false alarms
PPS	pulse per second
QA	quality assurance
QC	quality control
RTK	real time kinematic
Rx	ALLTEM receiver

ACRONYMS AND ABBREVIATIONS (continued)

Sd	standard deviation
SERDP	Strategic Environmental Research and Development Program
SNR	signal-to-noise ratio
TEM	time-domain electromagnetic
T-low	lower threshold
T-high	higher threshold
TMGS	Tensor Magnetic Gradiometer System
TOI	target of interest
Tx	ALLTEM transmitter
USGS	U.S. Geological Survey
UTEM	University of Toronto Electromagnetic (system)
UTM	Universal Transverse Mercator
UXO	unexploded ordnance
VETEM	Very Early Time-domain ElectroMagnetic (system)
YPG	Yuma Proving Ground, Yuma, AZ

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1.0 EXECUTIVE SUMMARY

1.1 OBJECTIVES OF THE DEMONSTRATION

Unexploded ordnance (UXO) is one of the most pressing problems facing the U.S. Department of Defense (DoD) and other government agencies that have lands that were once used for military training and are now closed or closing and being transferred to civilian or non-DoD government use. Cleanup of all UXO-contaminated lands using existing methods would be prohibitively expensive, so a great deal of effort is being directed to finding better ways to detect, locate and identify buried UXO. It is not sufficient to merely detect buried metal objects because many of these objects are not UXO and pose no hazards. In many cases of range cleanup, 70% or more of the cost consists of locating and removing harmless metal including soda cans, broken parts from agricultural equipment, and fragments of ordnance that exploded as designed. Among the primary geophysical methods for detection and classification are various time and frequency domain electromagnetic induction (EMI) systems and magnetometers.

This project follows Strategic Environmental Research and Development Program (SERDP) Project MM-1328. In that project one prototype magnetic system, the Tensor Magnetic Gradiometer System (TMGS) and two prototype EMI instruments, the Very Early Time-domain ElectroMagnetic (VETEM) system and the High Frequency Sounder, were evaluated. Subsequent to the evaluations, it was decided that a new multi-axis EMI system should be designed, built, and tested. Specifically, we recommended that we should build a multiple component, On-Time Time-Domain Electromagnetic system (ALLTEM) using a triangle current wave excitation and analyze the data by time-domain methods. This system is able to record at much later times the earth's electrical conductivity response, which has decayed to essentially zero. The new system is named ALLTEM because it is a time-domain electromagnetic (TEM) system in which the transmitter current is on all the time. In addition, we should develop analytical methods for extracting as much target information as possible from ALLTEM with the aim of identifying the targets and discriminating between UXO and harmless metal scrap.

After the successes of the ALLTEM at Yuma Proving Ground (YPG) in Yuma, AZ, in 2006 under sponsorship of SERDP, the Environmental Security Technology Certification Program (ESTCP) funded further development of the ALLTEM including demonstrations and validations at both YPG in 2009 and Aberdeen Proving Ground (APG) in Aberdeen, MD, in 2010. At these standardized controlled UXO test sites the Calibration Grid, the Blind Test Grid (BTG), and the Open Field Areas were surveyed (at APG these areas were the Direct and Indirect Fire areas). The Institute for Defense Analysis (IDA) gave high scores to the classification results from these surveys.

1.2 TECHNOLOGY DESCRIPTION

An advanced multi-axis EMI system, ALLTEM, has been specifically designed for detection and discrimination of UXO. This work has been funded by ESTCP (Project MR-200809). ALLTEM uses a continuous triangle-wave excitation that measures the target step response rather than the more common impulse response. Ferrous and nonferrous metal objects have opposite polarities. The system multiplexes through all three orthogonal (H_x, H_y, and H_z axes) transmitting loops and records a total of 19 different transmitting (ALLTEM transmitter [Tx]) and receiving (ALLTEM

receiver [Rx]) loop combinations with a spatial data sampling interval of 15 cm to 20 cm. Performance objectives for this project included upgrading the acquisition electronics and building a new sensor and cart out of lightweight fiberglass facing over plastic honeycomb core material (NOMEX). These upgrades were accomplished as well as upgrades to the data processing, inversion, and classification algorithms within Geosoft's Oasis Montaj platform. Data analysis has been streamlined within Oasis Montaj as routines specifically developed for ALLTEM in Oasis Montaj were used to analyze the ALLTEM data. This includes importing survey data; gridding; noise analysis for threshold determination; automatic selection of targets; batch inversion of selected targets using prolate, oblate, and ellipsoidal spheroids; and automatic statistical classification of inverted targets into clutter and targets of interest. Surveys are conducted in a "race track" manner with the sensor moving at 1 meter per second (m/s) along survey traverses separated by 0.5 m. The line spacing is typically determined by the smallest munitions of interest, which is usually a 20 mm, projectile.

1.3 DEMONSTRATION RESULTS

The ALLTEM has proved itself able to acquire data in the high temperatures of YPG in May and in the wet and cold areas, and the swamp lands of APG in February. Demonstrations have been successfully completed at both YPG and APG standardized test sites with very good scores. Ongoing data analyses indicate that ALLTEM is able to detect anomalous features and to automatically classify targets as being items of interest or not and then to discriminate between individual known munitions types.

1.4 IMPLEMENTATION ISSUES

An early limitation on data acquisition, loss of Global Positioning System (GPS) radio signals at YPG—common to many UXO investigations, was resolved by logging the raw GPS data at both the base station and at the rover on the moving ALLTEM sensor, post-processing the two data sets, and then reintegrating the results back with the ALLTEM data. An attitude heading and reference system (AHRS) has also been integrated into the acquisition stream and is used to generate more precise locations of sensor locations. The only other limitations on data acquisition is whether the tractor pulling the sensor can get over large rocks, boulders, vegetation, and very rough, irregular, or steep terrain. The ALLTEM cart now has a Lexan skid-plate that glides over most objects.

Technology transition efforts are in the proposal stage as Battelle Engineering and the U.S. Geological Survey (USGS) have developed plans for a phased transition of ownership and operation from USGS to Battelle over the next 2 years. This would involve application of the ALLTEM at three ESTCP Live Site demonstrations. The first site would be surveyed and the data processed by the USGS with Battelle looking on, the second site with both groups cooperatively working together on surveying and data processing, and the third site would be surveyed and the data processed by Battelle with the USGS acting in an oversight and advisory capacity.

To build an ALLTEM from scratch would cost about $60,000. Survey costs, based on recent field exercises at Camp Stanley Storage Activity near San Antonio, TX, are about $3000 per acre, including mob/demobilization, data acquisition, data analysis, and interpretation.

2.0 INTRODUCTION

2.1 BACKGROUND

UXO is one of the most pressing problems facing DoD and other government agencies that have lands that were once used for military training and are now closed or closing and being transferred to civilian or non-DoD government use. Cleanup of all UXO-contaminated lands using existing methods would be prohibitively expensive, so a great deal of effort is being directed to finding better ways to detect, locate and identify buried UXO. It is not sufficient to merely detect buried metal objects, because many of these objects are not UXO and pose no hazards. In many cases of range cleanup, 70% or more of the cost consists of locating and removing harmless metal including soda cans, broken parts from agricultural equipment, and fragments of ordnance that exploded as designed. Among the primary geophysical methods for detection and classification are various time and frequency domain EMI systems and magnetometers.

This project follows SERDP Project MR-1328. In that project one prototype magnetic system, the TMGS, and two prototype EMI instruments, VETEM and the High Frequency Sounder, were evaluated. Subsequent to the evaluations, it was decided that a new multi-axis EMI system using a triangle-wave excitation should be designed, built, and tested. Specifically, we recommended that we should:

- Build a multiple component ALLTEM using a triangle current wave excitation and analyze the data by time-domain methods. This system is able to record at much later times than VETEM, and the earth's electrical conductivity response has decayed to essentially zero at these later times. The new system is named ALLTEM because it is a TEM system in which the transmitter current is on all the time.
- Develop analytical methods for extracting as much target information as possible from ALLTEM with the aim of identifying the targets and discriminating between UXO and harmless metal scrap.

A preliminary demonstration of ALLTEM at YPG over the Calibration Lanes only was done in 2005. After some improvements, ALLTEM was demonstrated again over both the Calibration Lanes and BTG at YPG in May 2006. After data processing and inversion using our USGS-developed inversion algorithm, a target spreadsheet for BTG was submitted to IDA for scoring. The results were encouraging.

2.2 OBJECTIVE OF THE DEMONSTRATION

After the successes of the ALLTEM at YPG in 2006 under sponsorship of SERDP, ESTCP funded further development of the ALLTEM, including demonstrations and validations at both YPG in 2009 and APG in 2010. At these standardized controlled UXO test sites the Calibration Grid, BTG, and the Open Field Areas were surveyed (at APG these areas were the Direct and Indirect Fire areas). This report includes analysis of these data, the processes utilized, and the reported IDA scoring results.

In the demonstration work plans, the issue of added benefit when using the ALLTEM, was to be addressed by trying to answer the following questions:

- How well did ALLTEM detect the known targets?
- How many false positives were produced?
- How well did ALLTEM perform in locating each target?
- How well can one distinguish between ferrous, nonferrous, and mixed composition targets from ALLTEM data?
- How well can one estimate target shape?
- How well can one estimate target depth and orientation?
- How well can one distinguish between munitions and explosives of concern (MEC) and clutter?
- How efficient is ALLTEM in the field?

These questions are addressed in Sections 3 and 7.

2.3 REGULATORY DRIVERS

Individual states have their own regulations regarding the quality level of the cleanup of hazardous materials, sometimes including military munitions. The DoD has mandated that the cost to clean up current and formerly used sites must be reduced. The various military services have concluded that reducing the number of digs that must be completed to deem the site clean and remediated will significantly reduce the cost to complete at a particular site. These directives have resulted in a need for innovative technology that will achieve the goal of reducing costs. The development and success of tools like the ALLTEM are a major step forward toward reaching that goal.

3.0 TECHNOLOGY

3.1 ALLTEM TECHNOLOGY DESCRIPTION

The ALLTEM system is an on-time time domain EMI system that generates and records data in multiple channels in multiple directions (Figure 1). The system is unusual in that the transmitting (Tx) loops are driven by a continuous triangle current waveform and the resulting electromagnetically induced target responses are treated in the time domain. The measured quantity is the voltage in receiving (Rx) induction loops. This is theoretically equivalent to an integration of the voltage measured by a conventional EMI system that relies on a rapid current turn-off in a Tx loop. Practically, the use of a triangle wave results in much smaller early-time voltages induced in the Rx loops, reducing dynamic range demands on the receiver analog electronics and the digitizer. Another useful consequence is that ferrous and nonferrous targets show distinctly different waveforms (Wright et al., 2005 and 2006). The University of Toronto Electromagnetic (UTEM) system developed at the University of Toronto some years ago was a pioneer in the use of a triangle waveform in EMI systems (West et al., 1984) and has a theoretical advantage of emphasizing highly conducting targets buried in a less conductive host (Smith and Annan, 1998). ALLTEM is intended to obtain the advantages of triangle wave excitation in a system whose dimensions, characteristics, and geometry are appropriate to UXO applications.

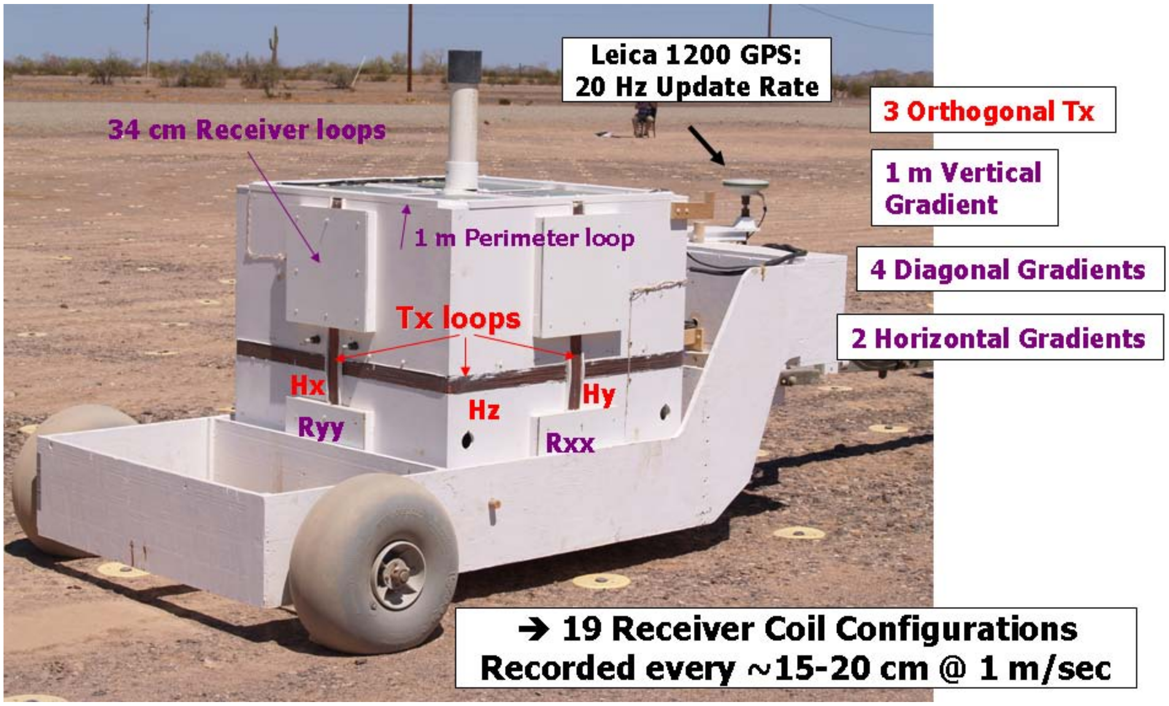

Figure 1. The ALLTEM 1 m sensor cube.

The Tx loops produce orthogonal magnetic fields in three directions (H_x, H_y, H_z).
The top and bottom faces contain a 1 m square Rx loop around the perimeter and four 34 cm printed circuit board Rx loops on 50 cm centers. Each vertical face has two 34 cm Rx loops to measure fields in the two horizontal directions (Hx and Hy). Because a transmitter is always on, opposite Rx loops are paired as gradiometers to cancel the primary field.

As a further aid to discrimination, we have designed ALLTEM with a multi-axis capability. There are three orthogonal Tx loops, an array of five Rx loops on the top and bottom of a 1 m cube, and Rx loops on each of the four vertical sides of the cube as shown in Figure 1. Voltage outputs of loops on opposite sides of the cube are subtracted to remove the large primary field response.

ALLTEM was tested at YPG in 2005 and 2006 (Figure 2) with good results.

Figure 2. ALLTEM at the YPG standardized UXO test area.

3.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

3.2.1 Advantages of ALLTEM

- Data is acquired in dynamic mode at 1 m/s, which is faster than repeat surveys with cued mode. Production at 1 m/s is about 1.5-2 acres/day at 0.5 m line spacing.
- As mentioned above, the triangle source wave reduces the required dynamic range of the electronics.
- Ferrous and nonferrous targets show distinctly different waveforms.
- AHRS allows for better determination of transmitter and receiver coil locations and orientations.

3.2.2 Limitations of ALLTEM

- It is not man-portable and must be pulled by a tractor.
- It does not perform real-time inversion of targets during acquisition. Data must be processed using custom Oasis Montaj ALLTEM graphic interface (gx’s). This is done fast and efficiently after acquisition but, currently, not during acquisition.
- ALLTEM is not waterproof but works well under a plastic tarp.

4.0 PERFORMANCE OBJECTIVES

Performance objectives are a critical component of a demonstration plan. They provide the basis for evaluating the performance and costs of the technology. Performance objectives are the primary criteria established by the investigator for evaluating the innovative technology. Meeting these performance objectives was essential for successful demonstration and validation of the technology.

Performance objectives for this ALLTEM demonstration are summarized in Table 1.

Table 1. Performance objectives.

Performance Objective	Metric	Data Required	Success Criteria
Quantitative Performance Objectives			
Detection of all munitions of interest	Percent detected of seeded items	• Location of seeded items • Prioritized dig list	Pd ≥ 0.95
Classification of anomalies	Percent of munitions classified as munitions and percent of clutter classified as clutter	• Prioritized dig list with probabilities	Percent of munitions and clutter classified correctly >95%
Discrimination by type of munitions of interest	Percent of targets correctly identified	• Prioritized dig list with a subset of probabilities that identifies type of target	Percent of munitions correctly identified >90%
Location accuracy	Average error in northing and easting for seed items	• Location of seed items surveyed to accuracy of 2 cm • Estimated location from analysis of geophysics data	ΔN and ΔE <0.10 m
Production rates	Number of acres of data collection per day Time required to analyze each target	• Log of field work and data analysis time accurate to 15 minutes	Survey: ~1.5 to 2 acres per day depending on survey speed Analysis time: <15 minutes per target
Qualitative Performance Objectives			
High quality data	Low system noise and few GPS dropouts	• Maps of gridded data	Maps of gridded data are “clean”.
Ease of use	Efficient and effective acquisition of ALLTEM data	• Feedback from technician on usability of technology and time required	Data is successfully acquired in specified time.

ΔN = Difference in northing from correct location   ΔE = Difference in easting from correct location   Pd = probability of detection

4.1 OBJECTIVE: DETECTION OF ALL MUNITIONS OF INTEREST

The effectiveness of the technology for detection and discrimination of munitions is a function of the degree to which all munitions of interest are detected with high confidence. The metric is to compare the number of targets detected to the number of actual targets present to determine the percent detected of seeded items. This was accomplished by the USGS only for the Calibration Grid data as this is the only data set for which we know the locations of all the seeded items. The data requirements are the locations of the seeded items in the Calibration Grid are required.

Locations refers to easting, northing, depth, and orientation (azimuth and dip). Additional data requirements for the BTG and Open Field area will be a prioritized dig list. The effectiveness of the technology for detection and discrimination of munitions is a function of the degree to which all munitions of interest are detected with high confidence. The objective was considered to have been met if more than 95% of the seeded targets were detected for each of the testing areas. In the APG BTG, as scored by IDA and rounded to the nearest 5%, the ALLTEM analysis resulted in a percent of detection (Pd) of UXO of 100% and a percent of false alarms (Pfa) of 25%. For the Direct Fire Area, the ALLTEM analysis resulted in a Pd of ordnance of 95% and a Pfa of 45%, which is not too good. For the Indirect Fire Area, the analysis resulted in a Pd of UXO of 95%.

4.2 OBJECTIVE: CLASSIFICATION OF ANOMALIES

The effectiveness of the technology for detection and discrimination of munitions is a function of the degree to which responses that do not correspond to targets of interest can be eliminated with high confidence. The metric is to determine the percent of actual munitions classified as munitions and the percent of actual clutter classified as clutter. The data requirements include a prioritized dig list with probabilities divided into groupings of clutter, munitions of interest, determination cannot be confidently made, and no determination can be made regarding the nature of the target. The objective will be considered to be met if the percent of munitions and clutter correctly classified exceeds 95%. Items noted as "Can't Say" and "Can't Analyze" will be treated as false positives. In the APG BTG, as scored by IDA, the ALLTEM analysis resulted in a percent of correct classification (Pcc) of UXO of 95%. In the Direct Fire Area, the ALLTEM analysis resulted in a Pcc of UXO of greater than 95%, and in the Indirect Fire Area, the analysis resulted in a Pcc of UXO of 95%.

4.3 OBJECTIVE: DISCRIMINATION OF MUNITIONS OF INTEREST AND CLUTTER

The effectiveness of the technology for detection and discrimination of munitions is a function of the degree to which individual responses can be identified with high confidence by munition type. The metric is to determine the percent of munitions identified correctly. The data requirements include a prioritized dig list with probabilities divided into groupings of clutter, labeled-munitions of interest, determination cannot be confidently made, and no determination can be made regarding the nature of the target. The objective will be considered to be met if the percent of munitions correctly identified exceeds 90%. This criterion is lower than the classification listed in Section 3.2.3 because previous analysis results showed that when the signal-to-noise ratio (SNR) is too low, accurate determination of munitions type is not always possible. The scoring metrics we have received from IDA have never broken out the exact numbers and types of munitions and clutter in order to reduce the number of times the test site areas need to be reconfigured. Even so, as indicated in Table 6, we do have some scoring metrics for the surveyed areas. In the BTG analysis, 25% of the detected clutter was called ordnance. In the Direct Fire Area analysis, 45% of the detected clutter was called ordnance. In the Indirect Fire Area analysis, 90% of the detected clutter was called clutter (i.e., only 10% of the clutter was called ordnance).

4.4 OBJECTIVE: LOCATION ACCURACY

The effectiveness of the technology for detection and discrimination of munitions is a function of the degree to which the anomalous responses are accurately located. The metric is to determine the average error of the northing and easting for seed items. The data requirements include a prioritized dig list with locations of anomalies in easting and northing surveyed to an accuracy of 2 cm. The objective will be considered to be met if the easting and northing locations of the seeded items have an error of less than 0.10 m. The effectiveness of the technology for detection and discrimination of munitions is a function of the degree to which the anomalous responses are accurately located. The estimated locations came from an analysis of the acquired ALLTEM data. The average errors in northing and easting locations for the APG Calibration Grid were 0.08 m and 0.20 m, respectively. Note that data locations are recorded every 0.20 m. Since the scoring for the BTG assumes use of the theoretical cell center positions and does not take into account the accuracy of the inverted positions and since the precise locations of the items in the Direct Fire and Indirect Fire areas are unknown, these criteria could not be comprehensively evaluated for these areas.

4.5 OBJECTIVE: PRODUCTION RATES

The effectiveness of the technology for detection and discrimination of munitions is a function of how quickly and efficiently the area of interest can be surveyed and the data analyzed and interpreted. The metric is the number of acres of data collection per day and the time required to analyze the data and determine the target properties. Data requirements include field logs describing the data acquisition schedule and data analysis logs detailing individual times for each target. The objective will be considered to be met if approximately 1.5 to 2 acres are surveyed per day. This is a function of the survey speed (1.0 m/s). The goal for analysis time is approximately less than 15 minutes on average per target identified. Table 2 presents a list of the APG test site areas surveyed and the actual times required for the ALLTEM to survey each area. These times include loss of production time due to waiting out loss of GPS real time kinematic (RTK) fixed mode, being stuck in the mud/soup (Indirect Fire Area) and having to be dragged out to more solid ground, and avoiding the steep walls of a small creek running through the survey area (Direct Fire Area). Part way through surveying the BTG we discovered a broken GPS antenna cable that had an intermittent connection when the cable swung as the tractor moved along. This caused some delays the first couple of days of surveying.

Table 2. ALLTEM APG survey production.

Area Surveyed	Acres Surveyed	Actual Survey Time (hrs)	Survey Time without Delays (hrs)	Estimated Acres Surveyed/ 8 Hr Day
Calibration Grid	0.27	2	1.5	1.44
BTG	0.5	3.5	2.5	1.60
Direct Fire Area	1.8	8	7.5	1.92
Indirect Fire Area	3.18	20	15	1.70
Total acres surveyed	5.75			

The last column in Table 2 indicates that, for an 8-hour day of surveying, the estimated production rates varied from 1.44 acres per day up to 1.92 acres per day. These rates are within the approximate bounds for achieving success for this survey objective.

4.6 OBJECTIVE: HIGH QUALITY DATA

The effectiveness of the technology for detection and discrimination of munitions is a function of the quality of the data. The metric of the measurement of high quality data is the degree to which systematic noise is present (or not) in the data and the GPS data is continuous. The data requirement includes maps of gridded data that would indicate the quality of the data in terms of both system noise and GPS dropouts. The objective will be considered to have been met if the gridded data maps show very little to no striping and there are no gaps in survey coverage indicating GPS dropouts. Generally, the ALLTEM data collected at APG met the specified criteria for achieving high quality data. As displayed in figures 14 through 17 and in the maps in Appendix 2, the acquired ALLTEM data show very little to no striping. However, as mentioned in Section 4.5, a broken GPS antenna cable created some dropouts during the first 1.5 days of surveying. These areas were resurveyed in order to provide a clean (no dropouts) data set for the analysis.

4.7 OBJECTIVE: EASE OF USE

The effectiveness of the technology for detection and discrimination of munitions is a function of how easy the ALLTEM system is to operate and the analysis software is to use. The measurement of ease of use is that the ALLTEM operator is able to efficiently and effectively acquire the data and that the data analysis using Oasis montaj goes smoothly. The data requirement here is feedback from the acquisition and analysis operators. The objective will be considered to have been met if the data is successfully acquired in the specified estimated time. The ALLTEM data acquisition system and software had been streamlined prior to deployment to YPG in 2009 and further streamlined for the deployment to APG in 2010. The ALLTEM data acquisition software (in LabView) and the data analysis and processing software (customized for Geosoft Oasis montaj) performed as designed and resulted in an efficient investigation. Two operators traded off running the data acquisition during each field day, and one operator handled the data analysis and processing in the evening and post survey operations. The system was very easy to use and operate as related by the operators in the cold and wet conditions that are typical in mid-March at APG.

5.0 ABERDEEN PROVING GROUND STANDARDIZED TEST SITE DESCRIPTION

The APG Standardized Test Site is located within a secured range area of the APG. The Aberdeen Area of APG is located approximately 30 miles northeast of Baltimore at the northern end of the Chesapeake Bay. The Standardized Test Site encompasses 17 acres of upland and lowland flats, woods, and wetlands. The site layout is presented in Figure 3.

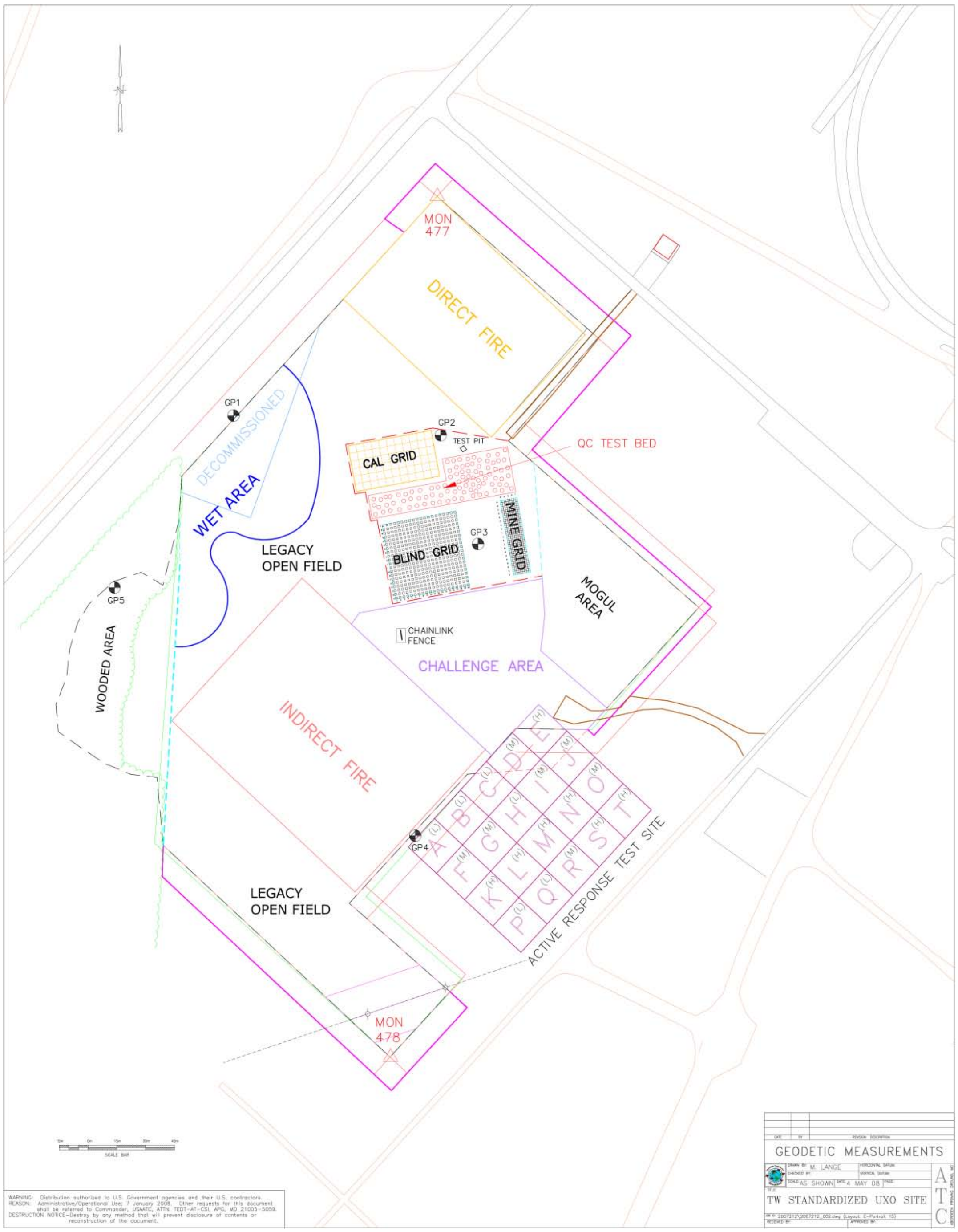

Figure 3. APG standardized UXO test site.

5.1 CALIBRATION LANES (0.30 ACRES)

The calibration portion of the test site consists of at least 19 lanes. This area contains 14 standard munitions items (Table 3) buried in six positions, with representation of clutter, at various angles and depths to allow demonstrators to calibrate their equipment.

Table 3. Munitions items in APG Calibration Grid.

Type	Description	Length (mm)	Width (mm)	Aspect Ratio	Weight (lbs)
20 MM	20 MM M55	25	20	1.25	0.25
40 MM	40 MM MK II	179	40	4.48	1.55
40 MM	40 MM M385	80	40	2.00	0.55
M42	SUBMUNITION	62	40	1.55	0.35
BLU-26	SUBMUNITION	66	66	1.00	0.95
BDU-28	SUBMUNITION	97	67	1.45	1.70
57 MM	57 MM M86	170	57	2.98	6.00
MK118	MK118 ROCKEYE	344	50	6.88	1.35
60 MM	60 MM M49A3	243	60	4.05	2.90
81 MM	81 MM M374	480	81	5.93	8.75
M230	2.75" ROCKET	761	75	10.15	18.20
105 MM	M456 HEAT Round	640	105	6.10	19.65
105 MM	105 MM M60	426	105	4.06	28.35
155 MM	155 MM M483A1	870	155	5.61	56.45

HEAT = high explosive anti-tank

5.2 BLIND TEST GRID (0.50 ACRES)

The APG BTG consists of a 1600 m^2 area located east of the open field range. The BTG is made up of the same type of munitions found in the Calibration Lanes and Open Field Site. Clutter items may include metal debris, rocks, vegetation roots, etc.

5.3 OPEN FIELD (5 ACRES)

The Open Field area is the largest of the test areas at the APG Standardized UXO Technology Demonstration Site. The area provides the demonstrator with a variety of realistic scenarios essential for evaluating sensor system performance. The scenarios and challenges found on this Open Field area consist of a gravel road, wet areas, dips, ruts and trees. Vegetation height varies from 15 to 25 cm. The Open Field areas surveyed at APG were the Indirect Fire Area and the Direct Fire Area. The Indirect Fire Area contains only three munition types that could be typically found at an impact area of an indirect fire weapons range. These are 81 mm and 60 mm mortars and 105 M60 projectiles. Munitions and clutter are placed in a pattern typical for a target area characteristic of these munitions. The Direct Fire Area contains only three munition types that could be typically found at an impact area of a direct fire weapons range. These are 25 mm, 37 mm, and 105 HEAT projectiles. Munitions and clutter are placed in a pattern typical for a target representative of these munitions.

6.0 TEST DESIGN FOR ALLTEM SURVEYS

This section provides a detailed description of the field tests that addressed the performance objectives described in Section 4.0.

6.1 CONCEPTUAL EXPERIMENTAL DESIGN

The overall design of this geophysics field investigation was to mobilize from Denver, CO, to the APG in about 3 days, survey the calibration grids and BTG on the first couple of full field days, and then survey the Indirect or Direct Fire Areas. The data acquired over the Calibration Grid was analyzed and compared to previous ALLTEM Calibration Grid survey results to verify system and analysis performance.

Key aspects of the overall approach for successful evaluation of the ALLTEM include all of the performance objectives listed in Table 1. These are good detection, classification, and discrimination results based on data that are accurately and precisely located and acquired and processed in a timely manner. The details of these aspects are discussed below in the following sections.

6.2 SITE PREPARATION

The APG UXO test site has been developed and prepared by the Army Environmental Center and APG personnel.

6.3 SYSTEM SPECIFICATION

As discussed in Section 3.1, the ALLTEM system is an on-time time domain EMI system that generates and records data in multiple channels in multiple directions resulting in a total of 19 channels. The Tx loops are driven by a continuous triangle current waveform and the resulting electromagnetically induced target responses are treated in the time domain. The measured quantity is the voltage in Rx induction loops.

The triangle waveform frequency can be varied under software control, but for several reasons we have settled on 90 Hertz (Hz) for field work. First, a half-period at 90 Hz is long enough to measure time decays for most UXO objects. Second, higher frequencies require higher driving voltages to maintain the same current amplitude. Third, while averaging waveforms over three cycles at 90 Hz greatly reduces 60 Hz interference, waveform data were averaged over only one cycle in order to increase our survey speed to 1.0 m/s. To minimize 60 Hz interference, the triangle wave frequency should be (n+1/2)•60 Hz where "n" is an integer, i.e., 30 Hz, 90 Hz, 150 Hz, etc. Finally, 90 Hz allows us to do some waveform averaging before recording, yet retain good spatial data density.

The Tx loops are each 66 turns and the current waveform that we apply to these loops is symmetric about zero amperes. In 2008 we replaced the CROWN power amplifier used to develop the system with a much more efficient Class D amplifier. This change enables us to increase the peak current to around 11 A while producing much less heat and without requiring as large a generator for power. The factor that determines the actual peak amperage is the

ambient temperature of the transmitter coils. In the middle of December in Denver the temperatures could be around 10-20EF. This has been observed to cause clipping of the transmitted signal when running at 12 A so we reduced the current output to 11 A. The peak Tx loop moment in this case is thus around 725 A m^2. Each Rx loop has 200 turns. A higher voltage gain is applied to the 34 cm Rx loop outputs than to the 1 m Rx loops so that the voltage inputs to the digitizer for the same target are comparable regardless of the Rx loop size.

The digitizer has eight simultaneous channels digitizing to 24 bits at a rate of 100 kilosamples/s. The 90 Hz triangle wave frequency is derived from the digitizer clock frequency to keep everything phase locked. A spatial data interval of 20 cm or less is used for each recorded channel along a line to ensure that each Rx gradiometer loop pair has more than one “look” at even the smallest and shallowest target it may pass over.

The 19 receiver names are based on which transmitter axis is energized, the size of the receiver, and the location of the receiver. These designations are described graphically in Figure 4.

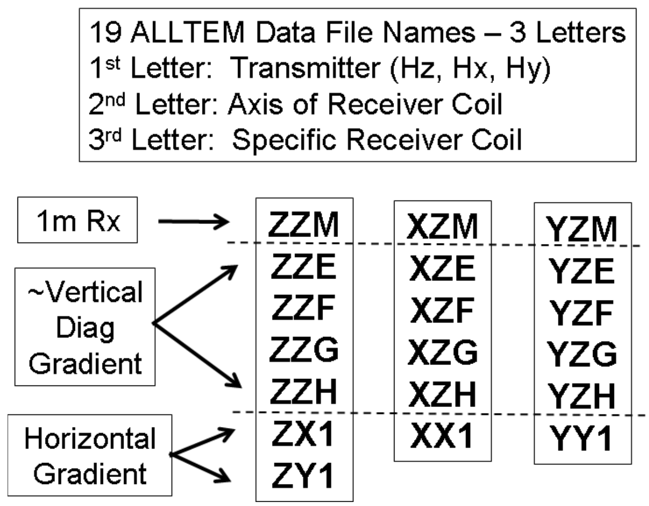

Figure 4. Naming convention for the ALLTEM transmitter and receiver combinations.

The data acquisition software, written using the National Instruments LabView workbench, allows the operator to select the receiver channels to display in real time and view raw waveforms or a strip-chart style display of sums and differences between amplitudes near the beginning and end of the waveforms.

6.3.1 ALLTEM Data Density Along a Survey Traverse

Figure 5 shows the spatial and timing relationships of the polarity sequences for a section of a survey line when the ALLTEM system is moving at 1.0 m/s with averaging of one group of three waveforms. Each polarity repeats its sequence every 255 m/s. Each transmitter is “on” for 3.30 cm of the 20 cm, and the approximate distance traversed between transmitter on-times (the time when all transmitters are turned off and the next turned on) is 0.011 m.

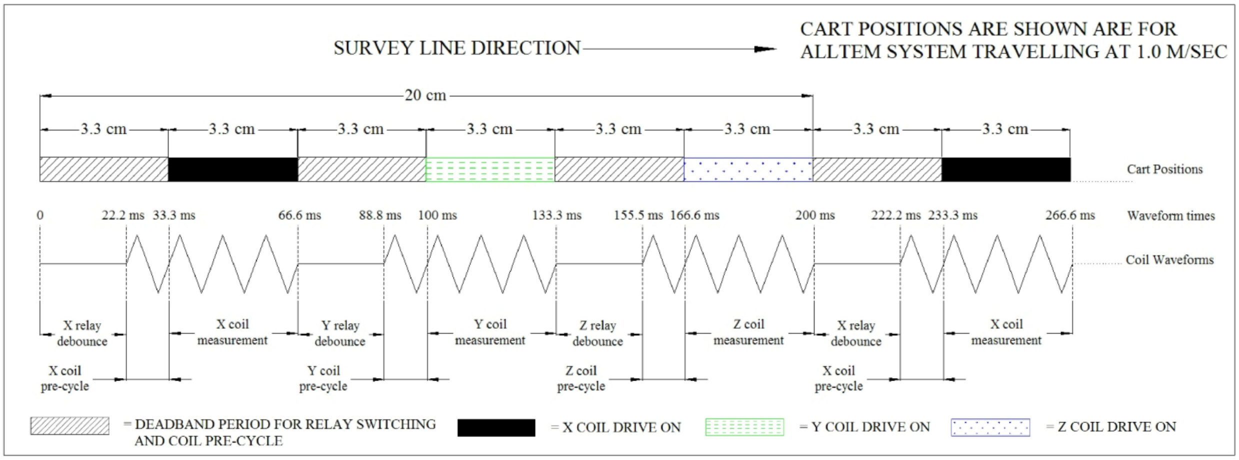

Figure 5. Schematic describing ALLTEM spatial data density along a survey traverse. Illustrated are the distances over which each drive coil is transmitting. Distances are in cm.

6.3.2 GPS Data Density

GPS data streams in from the Leica GPS 1200 rover asynchronously to the acquisition system and reports a location every 50 ms (Leica's 20-Hz update rate). The GPS values that are stored with the ALLTEM data are the positions that are closest to the middle of the waveform sampling period. The 0.20 m repeating transmitter sequences (when the three waveforms are averaged together and stored at the end of the sequence) provides the seven Hz transmitter-receiver combinations locations and six Hx and Hy transmitter-receiver combinations. It is common for TEM systems to implement binning of one or several "timegates" with digital or analog signal averaging to improve the SNR in each time gate. However, the ALLTEM records all the points along the waveforms at the full 10 µs/sample rate.

6.3.3 ALLTEM Calibration Activities

The methods used to confirm that the equipment was operating properly and that meaningful data were recorded included daily standardization checks of system functionality and system responses. The usual daily procedure included:

- *Warm up 15-30 minutes* – Allow the electronics and transmitter coils to stabilize.
- *Static standardization test* – Record background readings (500 samples) without a target.
- *Static standardization test* – Record with steel and brass balls (4-inch spheres) on top, sides of ALLTEM for about 500 samples each.
- *Dynamic standardization test (first day)* – Up and back, fast and slow traverses over surface-buried steel ball to check GPS positioning.

6.4 DATA COLLECTION PROCEDURES

6.4.1 Survey Scale

The areas surveyed at the APG UXO test site were the Calibration Grid (0.30 acres), the BTG (0.50 acres), the Direct Fire Area, and the Indirect Fire Area (approximately 5 acres). The survey procedure was to first mark and identify the corners of the survey areas as input to the survey planning and tracking software. Survey traverses were designed to have a 0.5 m separation. The data density along the traverses was approximately 0.15 to 0.20 m at a traverse speed of 1.0 m/sec. This survey speed and line spacing resulted in a production rate of approximately 1.5 acres per day.

6.4.2 Navigation and Orientation

To achieve high quality data, the ALLTEM uses an RTK GPS positioning, which provides consistent and georeferenced locations. The USGS owns a Leica GPS1200 system. The Leica has a pulse per second (PPS) output and a fast (20 Hz) update rate that are used to advantage. To achieve high real-time position accuracy, a GPS base station is used with a radio link to the rover unit mounted on the vehicle. For ALLTEM the GPS positions are part of the header in each data record. “RTK-Fixed” quality GPS data provide positions that are typically accurate to within ±2 cm. The Leica GPS1200 20 Hz update rate reduces latency issues and the remaining lag is compensated with software in post-processing.

The Crossbow Technologies AHRS is a solid-state system that utilizes proprietary Kalman Filter algorithms to determine stabilized roll, pitch, and heading angles in both static and dynamic conditions. The continuous gyro bias calibration output data are stabilized by long-term gravity and magnetic north references. The GPS antenna and AHRS unit are on a nose extension of the cart as shown in Figure 6.

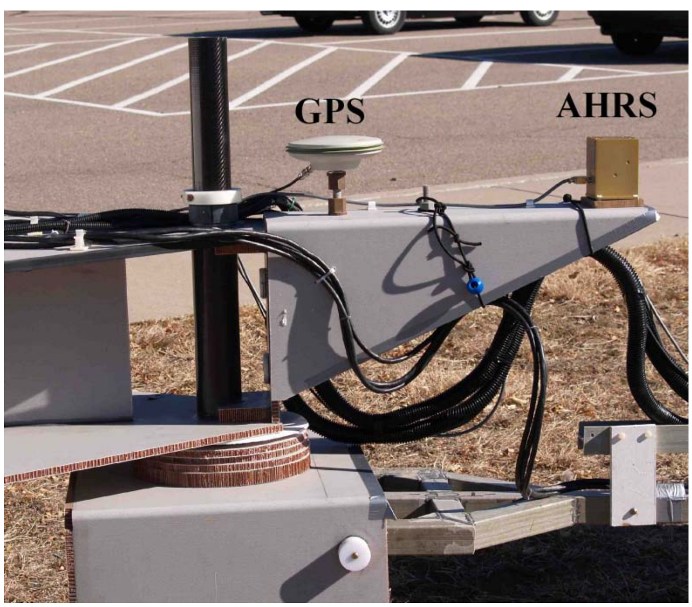

Figure 6. AHRS and GPS antenna on nose of new cart.

6.4.3 Data Recording and Archiving

Data for ALLTEM are initially recorded on the acquisition system hard drive. The raw data format for ALLTEM is an ASCII header containing system setting information, time stamp, and GPS and AHRS data followed by a fixed length of 24 bit summation averaged sensor data per record. Records for 19 Tx-Rx gradiometer channels (x, y, z, or diagonal component of the magnetic field) are typically written at rates of 2.5 to 5 per second.

6.4.4 ALLTEM Quality Control

The purpose of a quality management program is to define specific processes for ensuring that program and project objectives are properly defined and attained. The general objective of geophysical investigations is to efficiently detect, locate, and discriminate UXO for proper evaluation, recovery, and disposition.

Quality control (QC) is an appropriate evaluation performed by the provider of defined products to assure that the work conducted fully meets the prescribed requirements and complies with applicable laws, regulations, and sound technical practices.

Quality assurance (QA) is an appropriate management review of the overall effectiveness of the contractor's QC program, processes, and compliance of work by others. The QA procedures are the process by which the government fulfills its responsibility of being certain that QC is functioning and that the work was conducted as specified in the project-specific or programmatic work plan.

The USGS QC program that was followed during the demonstration of the ALLTEM at the APG includes comprehensive and consistent communication, careful management of data, and field observation of all procedures. Static and dynamic standardization QC checks were performed, including warming up the system and measurements with and without a calibration target. Data processing QC included visual and numerical checks on the data including field logs, data density along and across traverses, and signal losses due to GPS dropouts.

6.5 VALIDATION

No targets were dug at APG for validation purposes as all targets are considered to be seeded targets. We will wait until the ground truth for this configuration of the site is released.

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7.0 ALLTEM DATA ANALYSIS AND PRODUCTS

ALLTEM data analysis may be broadly divided into a preprocessing step using software developed in LabView that combines, filters, and finally exports particular time samples of data and then custom-designed data processing routines within Geosoft's Oasis Montaj platform that maps; grids; statistically analyzes; auto picks targets; writes out selected anomaly data; inverts for target characteristics such as location, orientation, and length and radius; and then classifies the results as not targets of interest or as targets of interest. Each of these processes is discussed below.

7.1 PREPROCESSING

The ALLTEM acquisition software continuously produces 19 separate data files—one for each receiver. Preprocessing the ALLTEM data involves running a LabView program that, operating in batch mode on all the data submitted up to a whole survey, removes the system response and background from the recorded waveforms, applies lowpass and bandpass filters, merges the GPS data (which is converted from latitude-longitude to Universal Transverse Mercator [UTM] easting-northing) with the recorded waveform data, averages the bipolar waveform (1111 samples are reduced to 555 samples), performs an integration of the area under the waveform to produce an indicator of composition (ferrous, nonferrous, and mixed), and finally exports ASCII data ready for import to Oasis montaj. In each file are the line number, the record number, easting, northing, and then 15 waveform time picks (amplitude values in volts) ranging from the beginning of the waveform (sample 0) to just before filtering effects at the end of the waveform (sample 535 or 5.35 ms). Sample values exported (recorded every 10 µs) include 0, 7, 22, 31, 45, 60, 75, 105, 135, 185, 250, 350, 450, 513, and 535. The sample 15 location shows a value indicating the amount of nonferrous material in the target.

7.2 TARGET SELECTION FOR DETECTION

For the APG demonstration, the ALLTEM operated over the Calibration Lanes, the BTG, and open field areas including the Direct Fire Area and the Indirect Fire Area. BTG, Direct Fire Area, and Indirect Fire Area results were submitted for scoring. Application of preprocessing, processing, and analysis tools that have been developed for the Oasis montaj platform are applied. The Oasis gx's import the LabView preprocessed data, apply dc offsets if necessary to the imported data, and then grid the data using Oasis routines. During gridding, noise and signal statistics are developed based on a target-free area within the data set. This statistical analysis is used to determine target locations and set target thresholds. The ALLTEM gx then applies some filters, if necessary, to sharpen the target location and then automatically selects target locations within all 19 receiver data sets. Target locations can be manually adjusted. Polygons are then created around each target location and the data within each target "patch" is selected and copied to a new subdirectory location for further analysis. The target patches can also be manually modified by the geophysicist analyzing the data. Once the target patches are finalized, the AHRS orientation corrections are applied to the data within each patch. The data are now ready to be processed by the inversion algorithms.

The ALLTEM data for the ZZM receiver for each of the four surveyed areas are presented in Figures 7, 8, 9, and 10. That portion of the data that was considered to be target-free with low to background noise levels to calculate the noise statistics is indicated for each area with a black polygon.

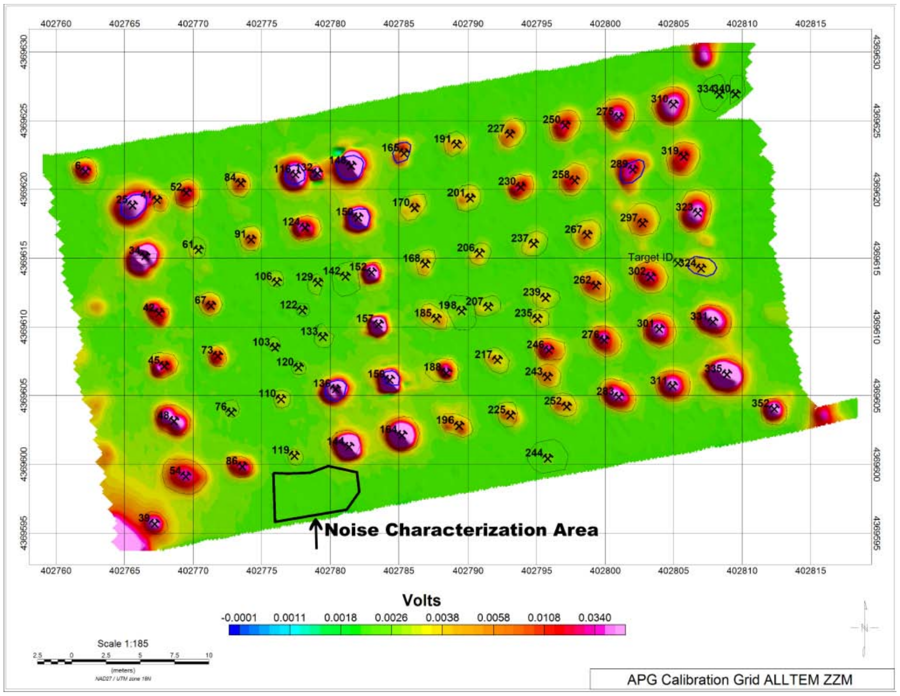

Figure 7. ALLTEM APG Calibration Grid data for the ZZM receiver polarization.
The survey data used to characterize the noise is indicated by the black polygon.

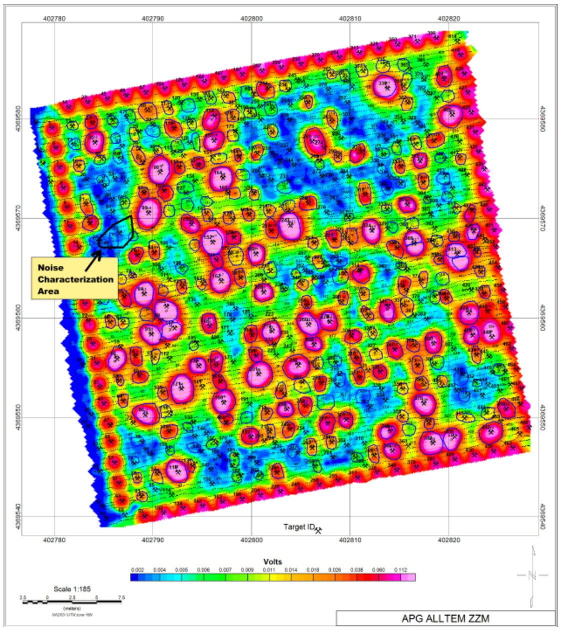

Figure 8. ALLTEM APG BTG data for the ZZM receiver polarization.
The survey data used to characterize the noise is indicated by the black polygon.

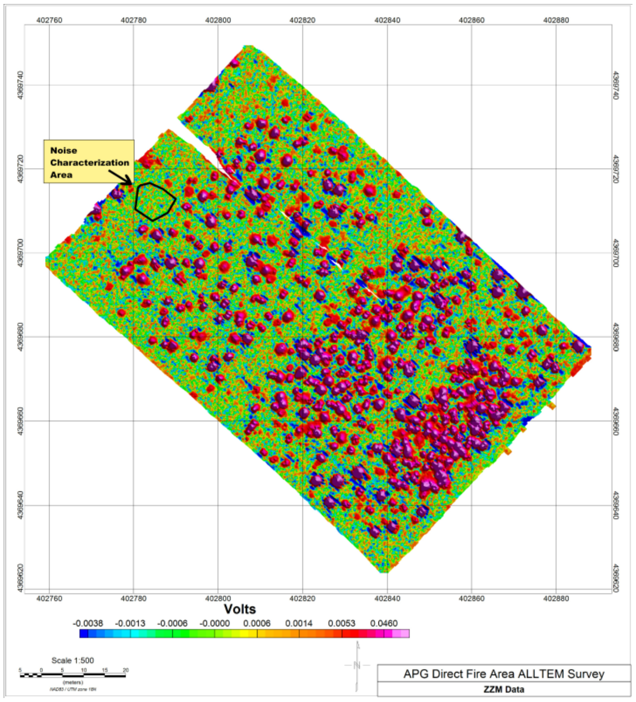

Figure 9. ALLTEM APG Direct Fire Area data for the ZZM receiver polarization.
The survey data used to characterize the noise is indicated by the black polygon.

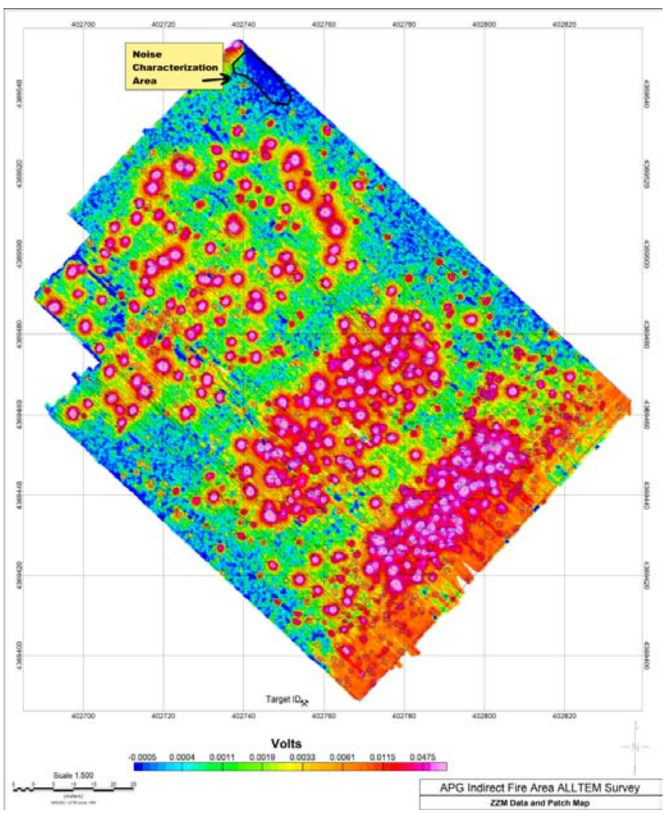

Figure 10. ALLTEM APG Indirect Fire Area data for the ZZM receiver polarization.
The survey data used to characterize the noise is indicated by the black polygon.

Anomaly selection uses thresholds that are calculated from background data identified in an apparent target-free zone in the survey area. Different thresholds are used for each receiver polarization based on its own noise characteristics. The thresholds are calculated as part of the data noise characterization process using the Shapiro-Wilkes test. The results are then stored in individual receiver polarization's data statistics file. The data stored are the Shapiro-Wilkes P-value (a form of confidence interval), the Shapiro-Wilkes W value, the mean and standard deviation (Sd) for a Gaussian distribution, and the high and low values of the noise (in volts). The ranges of the background/noise are stored at each time pick as well as the difference in the time picks. Table 4 lists a excerpt sampling of the background/noise thresholds for time picks and amplitude differences.

Table 4. Example data statistics from Denver Federal Center testing.

Data	450	513	547	45M450	45M513	45M547
Shapiro Wilks p-val	0.46625	0.35984	0.35600	0.06382	0.12241	0.05487
Shapiro - Wilks W	0.96638	0.96161	0.96141	0.93249	0.94331	0.92996
Mean Gaussian	0.05232	0.04998	0.04903	0.06617	0.06850	0.06945
Sd Gaussian	0.01469	0.01480	0.01447	0.00221	0.00230	0.00217
T-low	-0.10608	-0.10413	-0.10197	-0.07427	-0.07692	-0.07740
T-high	0.00145	0.00417	0.00391	-0.05806	-0.06009	-0.06150

Sd = standard deviation T-low = lower threshold T-high = higher threshold

7.3 PARAMETER ESTIMATION

As discussed in the previous section, the data in the selected target patches are corrected for orientation using the AHRS data and then submitted to the inversion algorithms. The ALLTEM inversion uses the Biot-Savart Law to model both the primary magnetic fields from the transmitter coils and those secondary magnetic fields, using reciprocity, transmitted by the target materials in the ground. The target response is currently modeled by single dipoles from prolate and oblate spheroids with one length and two widths and ellipsoids in which all three axes are free to vary.

The mean squared error in the best-fit modeled data is assumed to be due to variations from a non-ideal systematic response. These variations include components of the instrument response not accounted for by the model (drift, nonlinear response, etc.), components of target response not accounted for by the model, ambient electromagnetic (EM) noise, geologic noise, errors in instrument location, and attitude variations of the instrument. To estimate the uncertainty in the estimated parameters, each parameter is perturbed from its best-fit value until the mean squared error of the modeled data increases by the variance estimate of the data.

The number of data points is typically chosen to be less than ~1000. When selecting a set of coil combinations to use in the analysis, the set that carries the most (orthogonal) information is desirable. To select a subset of coil combinations from the recorded set of 19 coil combinations, selections are made in order of decreasing data variance until a single selection for each of the nine possible polarization combinations (i.e., [Txx, Rxx], [Txx, Rxy], etc.) has been made. Additional selections up to a user-defined total of 14 are made in order of decreasing data variance or high signal-to-noise characteristics.

An excerpt from an example inversion run log is presented in Figure 11. This is the run log for the ALLTEM data in cell A6 of the APG Calibration Grid. Cell A6 contains a 155 mm projectile buried at 1.08 m with an azimuth of 114.2 degrees and an inclination of 3.4 degrees. This type of projectile has a nominal diameter of 155 mm and thus a radius of 77.5 mm. The inverted radius from the ALLTEM data was 74 mm, the depth 0.91 m, azimuth 291.3 degrees, and inclination 0.6 degrees. These results are very close to the ground truth values for this target.

```
ModelNum: 1; Iteration: 14a; StepSize: 0.000000, ParamsErr: 0.003482, MSE: 0.161280.
 100.000,  8500000.000,        0.649,       -1.769,   -0.911,    0.170,    0.074,    0.074,   -0.000,
0.010,    0.561
ModelNum: 1; Iteration: 15a; StepSize: 0.000000, ParamsErr: 0.003482, MSE: 0.161280.
 100.000,  8500000.000,        0.649,       -1.769,   -0.911,    0.170,    0.074,    0.074,   -0.000,
0.010,    0.561
ModelNum: 1; Iteration: 16a; StepSize: 0.000000, ParamsErr: 0.003482, MSE: 0.161280.
 100.000,  8500000.000,        0.649,       -1.769,   -0.911,    0.170,    0.074,    0.074,   -0.000,
0.010,    0.561
Final Parameters:
---Mu---- ----Sigma---- ------X------ ------Y------ ----Z---- --Length- --Width1- --Width2- --Roll---
--Pitch-- ---Yaw---
 100.000,  8500000.000,   402769.403,  4369599.164,   -0.910,    0.169,    0.074,    0.074,    0.000,
0.010,    0.559
Target Azimuth:  291.337, Target Inclination:    0.599
Final MSE: 0.161278.

 Calculating Uncertainties...

Final Parameter Uncertainties:
---Mu---- ----Sigma---- ------X------ ------Y------ ----Z---- --Length- --Width1- --Width2- --Roll---
--Pitch-- ---Yaw---
   0.000, >200000000.000, >0000001.000, >0000001.000, >0001.00,    0.098,    0.090,    0.059,    0.000,
1.240, >0002.00
Target Azimuth Uncertainty:   71.047, Target Inclination Uncertainty: >0114.59

End inversion for target parameters...

Inversion used data StdDev/RMSData: 1.049114e+000, and RMSData:  2.798187e-001.

Inversion used 3780 data points, 14 coil combos, 9 time samples, and 30 spatial locations.
Operations Complete.
```

Figure 11. Excerpt of inversion run log for cell A6 (Patch 54) in the APG Calibration Grid.
This is a 155 mm projectile buried at 1.08 m, azimuth of 114.2E, and an inclination of 3.4E.
The inverted depth is 0.91 m, azimuth of 291.3E, and inclination of 0.6E.
The inverted depth is off by 0.17 m, azimuth by 177E, and inclination by 2.8E.

7.4 CLASSIFIER AND TRAINING

Training data for classification purposes came from the results of the analysis of the ALLTEM survey over the Calibration Grids at both YPG and APG. There are approximately four to six targets per munitions type buried in each of the Calibration Grids that provided useful information for the statistical classifier discussed in Section 8. The known Calibration Grid targets provided statistics on the location accuracy and correct determinations of depths, azimuths, and inclinations as well as the inverted lengths and radii.

The numerical inversion results from the ALLTEM survey over the APG Calibration Grid and also data from ALLTEM data acquired over the YPG Calibration Grid were used as the training data for the classification analysis of the BTG, Direct Fire, and Indirect Fire areas. These data are summarized in Figure 12.

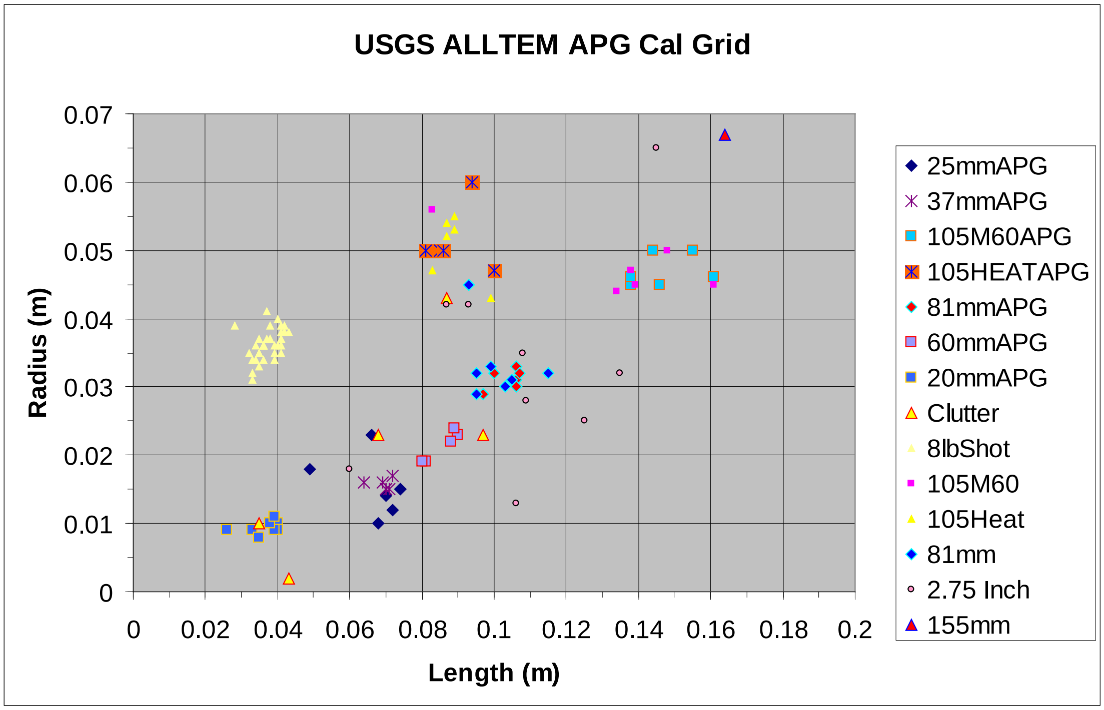

Figure 12. ALLTEM APG Calibration Grid numerical inversion results.

7.5 CLASSIFICATION

Classification of ALLTEM targets was achieved by making a statistical comparison between information derived from known targets acquired over the training grids (in this case, the Calibration Grids at YPG and APG) to the signal and noise characteristics and inversion analysis results for the unknown materials. Unknown materials were segregated into four main groups ranked by levels of confidence with an associated uncertainty that the anomalous material is not a target of interest (TOI). The four groupings will be High Confidence Non-TOI, Can't Make A Decision, High Confidence TOI, and Can't Analyze (which is usually due to low SNR for the ALLTEM). Signal and noise characteristics were derived from both the preprocessing analysis (ferrous, nonferrous, or mixed composition) and processing (shape information from inversion, SNR, target size [area of target] statistics). Much care was given in deciding what classification thresholds were used in recognition of the significantly higher costs of false negatives as compared to false positives.

A multiple comparison Student's T-test is made between known and unknown targets by using a probability density distribution to create a distribution showing the relation of known targets to unknown targets. For a given set of unknown parameters, the intervals that the T-distribution will cover at a given confidence level (α) are computed. The actual procedure is to simulate data around each set of known parameter values and perform a t-test on this simulated data. Unknown data are then compared to 100 simulations for each set of known ordnance parameters. Examples of the tables of known parameters are shown in Figure 13. An example of the Oasis menu item and classification results is shown in Figure 14.

155 mm		
Len	Width	Tau
0.137	0.079	-6.57171
0.174	0.075	-8.06782
0.151	0.08	-6.35774
0.148	0.068	-8.92571
0.169	0.074	-9.17839

105 mm M60		
Len	Width	Tau
0.154	0.05	-6.3586
0.154	0.039	-5.1389
0.148	0.05	-9.4961
0.134	0.044	-9.1316
0.161	0.045	-5.8998

BDU28		
Len	Width	Tau
0.038	0.029	-6.8052
0.04	0.03	-7.0142
0.04	0.03	-6.7626
0.038	0.028	-8.504

40 mm MK2 Projectile		
Len	Width	Tau
0.078	0.018	-6.126
0.085	0.017	-5.333
0.067	0.018	-5.603
0.07	0.02	-8.475

BLU-26		
Len	Width	Tau
0.031	0.024	-21.3626
0.035	0.022	-18.0124
0.031	0.021	-22.4924

81 mm Projectile		
Len	Width	Tau
0.093	0.038	-8.496
0.084	0.031	-7.267
0.111	0.032	-6.825
0.085	0.034	-6.881

60 mm Projectile		
Len	Width	Tau
0.077	0.027	-7.8028
0.085	0.021	-7.8926
0.088	0.024	-5.9094
0.083	0.021	-3.6281

M42-1 Submunitions		
Len	Width	Tau
0.029	0.015	-20.9203
0.029	0.017	-15.5508
0.021	0.013	-17.1652
0.022	0.013	-14.6351

40 mm Rifle Grenade		
Len	Width	Tau
0.027	0.024	-7.823
0.029	0.023	-7.467
0.036	0.027	-1.11361
0.032	0.027	-4.40274

Figure 13. Portions of tables of known parameters from the APG Calibration Grid.

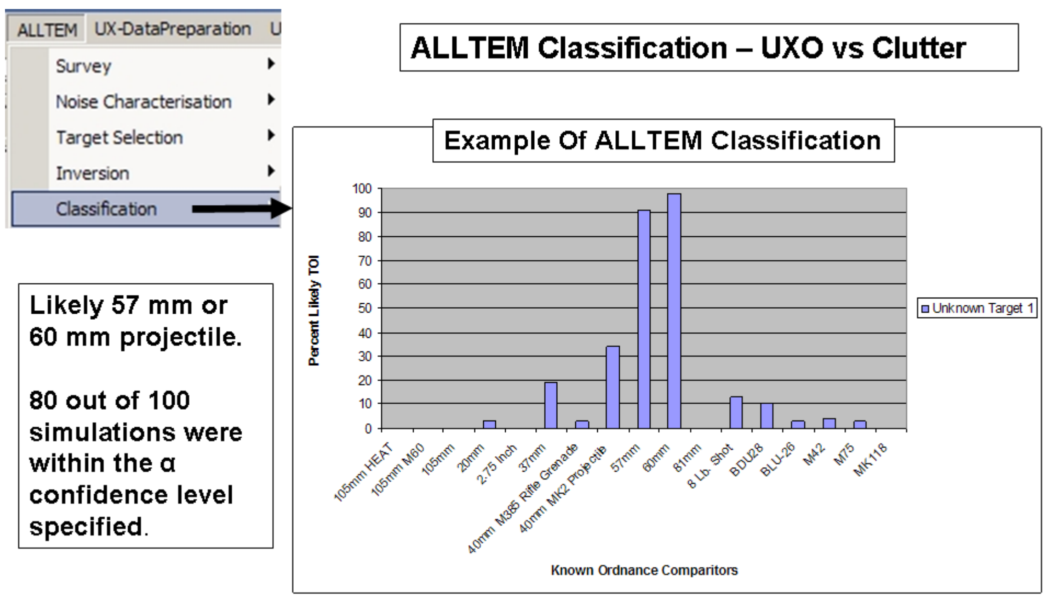

Figure 14. Classification example demonstrating a histogram of the classification result.

7.6 ALLTEM DATA PRODUCT

Table 5 presents a portion of the final data product for the APG BTG classification results. The full data products are contained in Appendix 4. Letters and numbers label the BTG cell locations and eastings and northings were used to label the Direct Fire Area and the Indirect Fire Area targets. As discussed in Section 7.5, the rankings were sorted by the probability that an item is of non-TOI character (clutter) and on down.

Table 5. Sample final data product.

ALLTEM APG 2010 BTG									
Cell	**Disc. Stage/Rank**	**Class**	**Type**	**Depth (m)**	**Azimuth (Deg)**	**Inclination (Deg)**	**Length (m)**	**Radius (m)**	**MSE**
a1	2	C		-0.04	267.9	17.8	0.027	0.017	*0.23*
a2	1	B							
a3	1	B							
a4	1	B							
a5	1	B							
a6	2	C		-0.03	198.0	-18.8	0.019	0.013	*0.20*
a7	2	C		-0.06	54.2	132.4	0.018	0.008	*0.62*
a8	3	O	25 mm	-0.06	173.8	5.0	0.052	0.018	*0.08*
a9	1	B							
a10	2	C		-0.07	166.5	-4.8	0.025	0.011	*0.51*
a11	1	B							
a12	2	C		-0.08	188.8	-1.0	0.033	0.011	*0.27*
a13	3	O	25 mm	-0.10	171.3	-0.9	0.061	0.011	*0.11*
a14	3	O	81 mm	-0.31	117.3	-164.9	0.107	0.034	*0.09*

MSE = mean-square error
1 = blank B = blank
2 = clutter C = clutter
3 – ordnance O = ordnance

The information in this table was provided to the project reviewer in order to determine if the metrics listed in Table 1 in Section 4 can be evaluated. This information allows a determination if all TOI were detected, items were correctly classified as non-TOI, TOI, Can't Say, and Can't Analyze, and TOI that could be discriminated could be properly identified. This table also includes eastings and northings so that the location accuracy metric can also be assessed.

8.0 PERFORMANCE ASSESSMENT

Table 6 presents the scoring of the ALLTEM classification results by the IDA. These data are the substance of the email communications received regarding the scoring of the ALLTEM data from the three unknown areas, the BTG, the Direct Fire Area, and the Indirect Fire Area.

Table 6. ALLTEM APG detection and classification scoring results.

Area	Scoring Summary (rounded to 5%)
BTG	Pd for UXO = 100%
	Pcc for UXO = 95%
	Pfa (blank squares called C or O) = 25%
	% false positives (detected C called O) = 25% False negatives showed no obvious trends re type of UXO or depth of burial
Direct Fire Area	For the Response (detection) stage: Pd for UXO = 95%
	% false positives (detected C called O) = 45% Pd (Depth: 0-4 x diam.) = 95%
	Pd (4-8 x diam.) = 95%
	Pd(>8 x diam.) = 90%
	For the Classification stage (only includes items detected in the response stage):
	PCC (detected O called O) = >95%
	PCC (0-4 x diam.) = >95% PCC (4-8 x diam.) = >95% PCC (>8 x diam.) = 95%
	No significant dependence on UXO type is observed
Indirect Fire Area	Pd for UXO = 95% Pcc for UXO detected = 95%
	Pd for Clutter = 65%
	Pcc for Clutter detected = 90%
	For UXO detection, Pd for items buried 0D to 8D = 95%
	Pd for items buried >8D = 85%
	For UXO classification, Pcc for items buried 0D to 8D = 95% Pcc for items buried >8D = 75%

The detection and classification results for the different field areas listed in Table 6 show that the achieved Pd and Pcc were 95% or higher for each these surveys. However, these high rates of detection and classification drop off when the items are buried at greater than eight times their diameter. Another concern is the number of clutter that were classified as ordnance, in particular for the Direct Fire Area. Further research is necessary to alleviate each of these issues.

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9.0 COST ASSESSMENT

A simple cost model for the ALLTEM technology was developed. Focus was on cost elements that are unique to the technology. For each cost element, data that can be obtained during the demonstration that is relevant for estimating the cost of that element are identified. Table 7 illustrates the cost elements that are relevant for the ALLTEM technology and identify what data were tracked in this project to validate the cost estimate.

Table 7. Cost model for the ALLTEM Demonstration Survey

Cost Element	Data to be Tracked	Estimated Costs
Instrument cost	Component costs and integration costs • Parts and labor	$70,000 (including overhead)
Mobilization and demobilization	Cost to mobilize to site • Each way	$1500 (not including salaries)
Site preparation	Site should be in condition such that a towed system may survey effectively	Site Dependent
Instrument setup costs	Unit: $ cost to unpack, set up, and calibrate Data requirements (derived from demonstration costs) • Hours required – 2 hours initial unpack\setup, 10 min to check Calib • Personnel required – 2 for setup & calibration • Frequency required – 2 daily QC checks before and after surveying	$500(?) for unpack and set up
Survey costs	Unit: $ cost per acre Data requirements (derived from demonstration costs) • Hours per acre – 4 hrs/acre for 5.75 acres Calibration, Blind Test, Direct Fire, Indirect Fire • Personnel required – 2	$2500/acre
Detection data processing costs	Unit: $ per hectare as function of anomaly density Data requirements (derived from demonstration costs) • Pre-processing – 2-4 hrs • Detection time required – 1-2 hrs/data set • Personnel required – 1 good	$50/acre
Discrimination data processing	Unit: $ per anomaly (derived from demonstration costs) • CPU time required - ~ 2 min/anomaly • Personnel required – 1 trained geophysicist	$20/anomaly

9.1 COST MODEL

Table 7 presents a summary cost model for the ALLTEM APG survey. The instrument cost estimate is based on actual costs of components and time associated with developing, manufacturing, and building the various parts of the system. These costs could change as material costs vary with supply and demand. The estimated mobilization and demobilization costs are based on the costs associated with this particular trip from Denver to APG and back. The survey cost estimate is based on the time spent surveying the different areas at APG. It took about 28 hours to survey the 5.75 acres. The preprocessing, detection, and discrimination costs are based on the time required to preprocess the data in LabView and then process the data in Oasis Montaj. As described in Section 7, using the ALLTEM Geosoft module required about 4 hours to import the data, invert the data, and classify the data for the BTG and about 90 minutes for the Calibration Grid. The Direct Fire Area took about 8 hours and the Indirect Fire Area 12 hours to import, process, invert, and classify. Note that the BTG, Direct Fire, and Indirect Fire

areas were each processed three times over the spring and summer of 2010 and resubmitted for scoring.

9.2 COST DRIVERS

Anticipated cost drivers include the time required to survey an area at 0.5 m line spacing with 0.20 m data density along the lines at 1.0 m/sec. Also, the time required dealing with problems such as GPS dropouts or mechanical breakdowns must be considered.

9.3 COST BENEFIT

The obvious benefit of a system such as the ALLTEM is the ability to reliably determine the nature of a buried target in the ground and then decide to dig it up or not dig it up. This is a very powerful tool because of the savings realized in reliably not digging a hole that would otherwise have had to be dug.

9.4 DEMONSTRATION COSTS

At an instrument production demonstration, the costs for the ALLTEM to perform would be similar to those listed in Table 7 except for the $70,000 instrument cost. In fact, the costs listed in Table 7 come from actual demonstration surveys at Camp Stanley, an Army storage depot located about 30 miles north of San Antonio, TX. A knowledge transition would also need to take place between the USGS and the contractor production team. The two basic areas requiring careful transition are care and maintenance of the acquisition electronics and other hardware and then the data processing including preprocessing in LabView and then processing, inversion, and classification in Geosoft’s Oasis montaj. We have written several manuals and also acquisition, nulling, and navigation simulation programs to help with this transition.

10.0 IMPLEMENTATION ISSUES

There are no issues deploying and operating the ALLTEM beyond use on appropriate terrain. The cart is also sealed against leakage. It actually floats when crossing deeper water bodies.

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11.0 REFERENCES

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APPENDIX A

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